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SEMICONDUCTOR LIFT PIN FOR DECHUCKING SUBSTRATES

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SEMICONDUCTOR LIFT PIN FOR DECHUCKING SUBSTRATES

BACKGROUND

The present invention relates to lift pins for dechucking a substrate held on a support in a process chamber.

In the manufacture of integrated circuits, a substrate is processed by process gas, for example a plasma, in a chamber. The substrate is typically supported in the chamber by a support, a portion of which may comprise a dielectric material covering an electrode. The electrode may be charged, for example with a DC voltage, to electrostatically hold the substrate. Lift pins may be used to lift and lower a substrate onto the support in the process chamber. Typically, a robotic arm transports the substrate into a process chamber where the substrate is deposited on lift pins that extend upwardly through the chuck. The lift pins are then lowered into a lower portion of the process chamber to deposit the substrate on the support. Thereafter, the robotic arm is withdrawn from the chamber. After processing of the substrate, the DC voltage applied to the chuck electrode is terminated to release the substrate, and the lift pins are raised upwardly through holes in the chuck to lift the substrate off the chuck by pushing up against the substrate. The robotic arm is then reinserted to withdraw the processed substrate from the chamber.

One problem with conventional lift pins arises when the lift pins attempt to lift the substrate off the chuck. Residual electrostatic charge in the substrate generates attractive electrostatic forces between the substrate and the chuck, that cause the substrate to adhere to the chuck, even when the voltage to the chuck is terminated. The upwardly pushing lift pins can damage or break the substrate. Lift pins are typically composed of electrically insulative material, which trap residual electrostatic charge in the substrate, causing the substrate to stick to the chuck as the lift pins are pushed against the substrate, resulting in damage or breakage of the substrate.

One solution is to use electrically grounded metal lift pins that allow the residual charge in the substrate to discharge through the lift pins. However, the metal

pins may allow the high frequency RF energy used to sustain the plasma in the chamber, to propagate through the metal pins and into the lower portion of the chamber. This results in plasma formation in the lower portion of the chamber, causing erosion of the metal parts therein, and wasting the power used to generate the plasma. Also, the plasma heats up the lower portion of the process chamber, and causes deposits to form on the components therein.

Therefore, there is a need for a lift pin which allows discharging of residual electrostatic charge in a substrate. It is further desirable for the lift pins to reduce propagation of the RF energy into the lower portion of the process chamber.

SUMMARY

The present invention satisfies these needs. In one aspect of the invention a lift pin capable of dechucking a substrate on a support in a chamber comprises a body comprising semiconducting material.

In another aspect of the invention, a substrate processing chamber comprises a substrate support comprising an electrode, a dielectric at least partially covering the electrode, and a lift pin comprising a semiconducting material, a gas distributor, a gas energizer, and a gas exhaust, whereby a substrate received on the support may be processed by gas introduced through the gas distributor, energized by the gas energizer and exhausted by the gas exhaust and may thereafter be dechucked by the lift pin.

In another aspect of the invention, a method of dechucking a substrate in a chamber comprises providing a support in the chamber, the support comprising a lift pin comprising semiconducting material, supporting the substrate on the support, and moving the lift pin to contact the substrate.

In another aspect of the invention, a method of processing a substrate in a chamber comprises providing a support in the chamber, the support comprising an electrostatic chuck and a lift pin comprising semiconducting material, generating an electrostatic chucking force to support the substrate on the support, providing

energized process gas in the chamber, and moving the lift pin to contact the substrate to dechuck the support.

In another aspect of the invention, a method of fabricating a lift pin usable in a substrate support in a chamber comprises providing a body comprising semiconducting material and forming the body into the lift pin.

DRAWINGS

These features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings which illustrate exemplary features of the invention. However, it is to be understood that each of the features can be used in the invention in general, not merely in the context of the particular drawings, and the invention includes any combination of these features, where:

Figure 1 is a schematic sectional side view of a substrate processing apparatus according to the present invention;

Figure 2 is a schematic sectional side view of a lift pin according to the present invention;

Figure 3 is a schematic sectional side view of another version of a lift pin according to the present invention;

Figure 4 is a schematic sectional side view of another version of a lift pin according to the present invention; and

Figure 5 is a schematic sectional side view of another version of a lift pin according to the present invention.

DESCRIPTION

The present invention relates to a lift pin for a support. The description represents illustrative embodiments of the invention and is not intended to limit the invention.

An exemplary apparatus **10** suitable for processing of a substrate **15**, such as a semiconductor wafer, is shown in Figure 1. The apparatus is particularly useful for energized gas processes, such as plasma processes, where RF currents are used to generate a plasma for processing the substrate. Examples of such plasma processes include plasma enhanced chemical vapor deposition, sputtering processes, ion implantation processes, and plasma etching or reactive ion etching processes.

The apparatus **10** generally comprises an enclosed process chamber **20** having an upper portion **22**, a lower portion **24**, and surrounded by walls **25**. Process gas may be introduced into the chamber **20** through a gas distributor **30**. The process gas may be energized by inductive coupling to form a plasma in the upper portion **22**, using, for example, an inductor coil **35** wound around the chamber **20**. Alternatively or in addition, energy may be capacitively coupled to the process gas by process electrodes **40a**, **40b** in the chamber **20**. An exhaust **45** is provided for withdrawing spent process gas and process gas byproducts from the process chamber **20** and for generating a low pressure in the chamber **20**.

The apparatus **10** may also include an electrostatic chuck **50** to hold the substrate **15** during processing of the substrate **15**. A typical electrostatic chuck **50** comprises an electrostatic member **55** including one or more electrodes **60** at least partially covered by a dielectric material. The chuck **50** is secured to a support **65** in the process chamber **20**. An electrical connector **70** electrically connects the electrodes **60** in the chuck to a conventional electrostatic chuck power source **75** suitable for powering the chuck.

In energized gas processes, a substrate **15** is placed on the support **65** and the electrostatic chuck **50** is electrically biased with respect to the substrate **15** by the chuck power source **75**. Process gas is introduced into the process chamber

20 via the gas distributor **30**. A plasma can be inductively formed from the process gas by applying a high frequency RF source current to the inductor coil **35** using a plasma power source **80**, and/or capacitively formed by applying a high frequency RF current to the process electrodes **40a**, **40b** using a bias power source **82**. In one version, the electrode **60** in the electrostatic chuck **50** may be used as one of the process electrodes **40a**. The RF frequencies used to inductively or capacitively form the plasma and attract the plasma to the substrate **15**, are typically above 1.5 MHz, and more typically from about 1.8 MHz to about 60 MHz. In plasma processes, the voltage applied to the electrode **60** of the chuck **50** causes electrostatic charge to accumulate in the electrode, and the plasma in the chamber **20** provides electrically charged species having opposing polarity which accumulate in the substrate **15**. The accumulated opposing electrostatic charge results in an attractive electrostatic force between the substrate **15** and the electrode **60** in the chuck **50**, causing the substrate **15** to be electrostatically held to the chuck **50**. Bipolar chucks having two electrodes (not shown) operate by electrically biasing the two electrodes with respect to one another to generate an electrostatic charge that holds the substrate **15** to the chuck **50**. In alternative chamber versions (not shown), the capacitively generated plasma can also be enhanced by electron cyclotron resonance or magnetically enhanced by a magnetic field generator, such as a permanent magnet or an electromagnetic coil, which provide a magnetic field that may increase the density and uniformity of the plasma in the plasma zone. The magnetic field may also comprise a rotating magnetic field with the axis of the field rotating parallel to the plane of the substrate **15**.

The lower portion **24** of the process chamber **10** comprises a lift pin assembly **85** that may be used to lift and lower the substrate **15** onto the electrostatic chuck **50**. In the version shown in Figure 1, the lift pin assembly **85** comprises a support **90**, such as, for example, a C-shaped ring, with a plurality of lift pins **95** mounted around the support **90**. The lift pin assembly **85** may comprise a plurality of lift pins **95**, such as for example three or four, which are mounted symmetrically on the support **90** so that the substrate **15** can be lifted off the chuck **50** by a uniformly applied pressure. The support **90** is attached to lift bellows **100** that can lift and lower the support **90**, thereby lifting and lowering the lift pins **95** through the holes in the chuck **50**, which in turn lift and lower the substrate **15** off the chuck **50**.

A lift pin **95** for dechucking a substrate **15** on a support **65** is shown in Figure 2. In one version, the lift pin **95** is able to dechuck a substrate **15** held to a chuck **50** by residual electrostatic charge, by passing the charge to a current sink **105**. Generally, the lift pin **95** comprises a movable elongated member **110**. Optionally, the member **110** may have a tip **115** suitable for lifting and lowering the substrate **15** off the chuck **50**. When multiple lift pins are provided on the lift pin assembly **85**, at least one lift pin **95** is capable of forming an electrically conductive path **120** between the substrate and the current sink **105**. An RF voltage reducer **125**, such as for example a resistor having a resistance of from about 1 MΩ to about 10 MΩ, is coupled in series along the electrically conductive path **120** of the elongated member **110**. The resistor **125** allows substantially all the residual electrostatic charge in the substrate **15** to flow therethrough, substantially without allowing RF currents, used to form a plasma in the process chamber and to attract the plasma to the substrate, from flowing to the current sink **105**. Thus, the undesirable RF propagation through the lift pins which can result in plasma formation in the lower portion of the chamber and cause deposits to form on the support components is substantially avoided, as discussed in U.S. Patent 5,900,062 which is incorporated herein by reference in its entirety.

To dechuck a substrate **15** held to an electrostatic chuck **50** by low frequency electrostatic residual charge, the lift pins **95** are raised and electrically contact the substrate **15**. When a resistor **125** is used, the residual electrostatic charge in the substrate **15** discharges to the current sink **105**, while the passage of voltage caused by the high frequency RF currents used to generate or attract the plasma to the substrate, is substantially reduced, thereby resulting in substantially no plasma formation in the lower portion of the chamber. The substrate **15** is lifted off the chuck after the residual electrostatic charge in the substrate **15** is substantially discharged. The lift pins **95** may be continuously raised in an upward direction while the residual electrostatic charge in the substrate **15** is discharging to the current sink **105** to speed process throughput. Thus, the residual charge in the substrate **15** may be discharged to the current sink **105** in a sufficiently short time that the substrate **15** is released from the chuck **50** without breaking, while the lift pins move in an upward direction.

In one version, the lift pin **95** comprises an elongated member **110** comprising an electrically conductive upper portion **130**, a central portion **135** comprising the resistor **125**, and an electrically conductive lower portion **140** suitable for electrical connection to the current sink **105**, as shown in Figure 2. The electrically conductive upper portion **130** and lower portion **140** are made from metals or other rigid conductive materials having low resistance to current flow. The upper portion **130** can also comprise a layer of a flexible material that prevents damage to the substrate **15** when the lift pins **95** are pushed upwardly against the substrate **15**.

In one version a central portion **135** of the lift pin **95** comprises a rigid electrically insulative shell sized to house the resistor **125**. The insulative shell is mechanically connected to the upper portion **130** and the lower portion **140** so that the lift pin **95** can withstand a load when lifting the substrate **15** from the chuck **50**. The insulative shell may be made from any electrically insulative polymer, such as polyimide, polyketone, polyetherketone, polysulfone, polycarbonate, polystyrene, nylon, polyvinylchloride, polypropylene, polyetherketones, polyethersulfone, polyethylene terephthalate, fluoroethylene propylene copolymers, silicone, and rubber. The insulative shell may be resistant to temperatures in excess of 50°C, or in excess of 100°C, or even in excess of 300°C, so that the lift pin **95** can be used for high temperature processes. Typically, the insulative shell has a resistivity ranging from about 10^{13} Ω cm to 10^{20} Ω cm. The thickness of the insulative shell is typically from about 1 mm to about 5 mm.

In one version, the resistor **125** comprises a resistor coupled in series with the electrically conductive path **120** defined by the lift pin **95**. The resistor **125** has a resistance sufficiently elevated to reduce the voltage caused by the RF currents flowing therethrough by at least about 50%, and more preferably at least about 75%. The resistor **125** has a resistance sufficiently elevated that the resistor is capable of discharging residual electrostatic charge in the substrate while causing a drop in voltage of the RF currents used to generate the plasma or attract the plasma to the substrate, to a voltage level sufficiently low that the high frequency RF currents do not form a plasma in lower portions of the chamber.

The resistance of the resistor **125** affects the length of time taken for discharge of the residual electrostatic charge in the substrate **15**. This occurs because the resistor **125**, substrate **15**, and the chuck **50**, form an RC circuit having a time constant R*C seconds, where C is capacitance in farads, and R is resistance in Ω. The time constant is the number of seconds required for the capacitor to reach about 63% of its full charge after a voltage is applied. Thus, depending on the capacitance of the substrate **15** and chuck **50**, the value of the resistor is selected to obtain the desirable time constant as limited by the speed with which the lift pin **95** lifts the substrate **15** off the chuck **50**. Typically, the electrostatically charged substrate **15** and chuck **50** form a capacitor having a capacitance of about 1,000 pF. To determine a suitable resistance value for the resistor, the RC time constant equation is solved to determine the resistance value equal to the ratio of a desired time constant to the capacitance. Preferably, the resistance of the resistor at least about .5 MΩ, and more preferably from about 1 MΩ to about 100 MΩ, and most preferably from about 1 MΩ to about 10 MΩ, to achieve a 10 millisecond discharge period.

Selection of the type of resistor depends on the operating frequencies of the RF currents and the residual electrostatic charge in the substrate **15**. Resistors change in their resistance value when subjected to RF alternating currents. The change in resistance with increasing frequency occurs because resistors have some inductance and capacitance in addition to the resistive component. The effect of frequency on resistance varies with the resistor construction. Wire-wound resistors typically exhibit an increase in their impedance with frequency. In composition resistors, capacitances are formed by the many conducting particles which are held in contact by a dielectric binder. Film resistors have the most stable RF performance, with their AC impedance remaining constant until about 100 Hz and decreasing at higher frequencies, and their decrease in DC resistance at higher frequencies decreasing for increasing resistances. Also, the smaller the diameter of the resistor, the better is its frequency response. Most RF resistors have a length to diameter ratio of 1:4 to 10:1.

In another version, such as the version shown in Figure 3, the resistor **125** comprises a body **126** comprising semiconducting material. The semiconducting

material has a resistance selected so that the lift pin **95** can discharge residual electrostatic charge in the substrate **15** while reducing the amplitude of RF currents flowing therethrough to a level sufficiently low that the RF currents passed through do not form a plasma in the lower portions of the chamber **20**. The path length and resistance of the semiconducting material is selected to operate as a resistor, as described above. For example, the semiconducting material may be sufficiently thick to provide an effective resistance to a current flowing therethrough of at least about .5 MΩ, and more preferably from about 1 MΩ to about 10 MΩ, and most preferably about 10 MΩ. In one version, the semiconducting material has a resistance that is sufficiently elevated to reduce the amplitude of the RF currents flowing therethrough by at least about 50%, and more preferably at least about 75%.

Figures 4 and 5 show different versions of lift pins **95** comprising bodies **126** comprising semiconducting material. As shown in Figure 4, the lift pin **95** may comprise a solid body of semiconducting material making up the resistor **125**. The version of Figure 4 is relatively easy to manufacture and possesses high strength. As shown in Figure 5, the body of semiconducting material may comprise a hollow section **150**. The hollow section **150** allows for tailoring of resistance values and also allows for the installation of other electronic devices or features within the lift pin **95**, if desired. In the versions shown in Figures 4 and 5, the lift pin **95** may be provided with an electrically conductive upper portion and/or an electrically conductive lower portion or the entire lift pin **95** may comprise semiconducting material. Alternatively, spaced semiconducting portions can be connected by conducting portions. In another version, the resistor **125** comprises a combination of a conventional resistor in series or in parallel with a semiconducting material.

By "semiconducting material" it is meant a material whose electrical conductivity is intermediate between that of a metal and an insulator. For example, the electrical conductivity of a semiconducting material may be from about 10^3 to about 10^{-9} ohm^{-1} cm^{-1}. Suitable semiconducting materials include silicon carbide, titanium diboride, titanium oxide, aluminum nitride, silicon, germanium, tellurium and combinations thereof and any other material that can be doped to form a semiconductor material. Conventional ceramic casting, molding, and pressure-forming processes can be used to fabricate a semiconductor structure shaped like the lift pin

95. For example, a semiconducting lift pin **95** can be fabricated by forming a slurry of silicon carbide and pouring the slurry into a mold corresponding to the desired shape of the lift pin **95**. After drying the component, the silicon carbide lift pin **95** is fired to a temperature sufficiently elevated to sinter the silicon carbide to form a hard semiconductive silicon carbide lift pin **95**. Conventional machining techniques can be used to shape, smooth, or machine holes in the lift pin **95** so that the lift pin can be attached to the support **90**. Mixtures of ceramic insulative powders and conductive metal powders can also be used to provide the desired resistance for the semiconductor material.

In an exemplary version, the lift pin **95** comprises a solid body **126** comprising silicon carbide having a resistance of 1 to 10 mega ohms. Lift pins **95** comprising a solid semiconducting material remove the need for additional components, which can make the system more reliable.

The resistor **125** may also comprise a resistive-inductive circuit that includes a combination of an inductor and a resistor, coupled in series with the electrically conductive path **120**. The inductance of the inductor, and the resistance of the resistor, are selected to provide a combination resistive-inductive circuit having the desired characteristics as described above. For example, the resistance of the resistor may be from about 100 kΩ to about 100 MΩ, and more preferably from about 10 MΩ to about 100 MΩ, and the inductance values for the inductor is from about 10 μH to about 1000 μH, and more preferably from about 100 μH to about 500 μH, to achieve a 10 millisecond discharge period.

While the present invention has been described in considerable detail with reference to certain preferred versions, many other versions should be apparent to those of ordinary skill in the art. For example, the support may be used in other substrate processing chambers. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

What is claimed is:

1. A lift pin capable of dechucking a substrate on a support in a chamber, the lift pin comprising:

a body comprising semiconducting material.

2. A lift pin according to claim 1 wherein the semiconducting material is sufficiently thick to provide a resistance over the length of the lift pin of at least about 0.5 MΩ.

3. A lift pin according to claim 1 wherein the semiconducting material is sufficiently thick to provide a resistance over the length of the lift pin of from about 1 MΩ to about 10 MΩ.

4. A lift pin according to claim 1 wherein the semiconducting material is sufficiently doped to provide a resistance over the length of the lift pin of at least about 0.5 MΩ.

5. A lift pin according to claim 1 further comprising a conductive upper portion and a conductive lower portion connected to the body.

6. A lift pin according to claim 1 wherein the semiconducting material comprises silicon carbide.

7. A lift pin according to claim 1 wherein the semiconducting material comprises titanium diboride.

8. A lift pin according to claim 1 wherein the body comprises a unitary piece of semiconducting material.

9. A lift pin according to claim 1 wherein the body is solid.

10. A lift pin according to claim 1 wherein the body is hollow.

11. A substrate processing chamber comprising:

a substrate support comprising an electrode, a dielectric at least partially covering the electrode, and a lift pin comprising a semiconducting material;

a gas distributor;

a gas energizer; and

a gas exhaust,

whereby a substrate received on the support may be processed by gas introduced through the gas distributor, energized by the gas energizer and exhausted by the gas exhaust and may thereafter be dechucked by the lift pin.

12. A substrate processing chamber according to claim 11 wherein the lift pin is adapted to provide an electrically conducting path between the substrate and a current sink.

13. A substrate processing chamber according to claim 11 wherein the semiconducting material is sufficiently thick to provide a resistance over the length of the lift pin of at least about 0.5 MΩ.

14. A substrate processing chamber according to claim 11 wherein the semiconducting material is sufficiently thick to provide a resistance over the length of the lift pin of from about 1 MΩ to about 10 MΩ.

15. A substrate processing chamber according to claim 11 wherein the semiconducting material is sufficiently doped to provide a resistance over the length of the lift pin of at least about 0.5 MΩ.

16. A substrate processing chamber according to claim 11 wherein the semiconducting material comprises silicon carbide.

17. A substrate processing chamber according to claim 11 wherein the semiconducting material comprises titanium diboride.

18. A substrate processing chamber according to claim 11 wherein the lift pin is formed from a unitary piece of semiconducting material.

19. A method of dechucking a substrate in a chamber, the method comprising:

providing a support in the chamber, the support comprising a lift pin comprising semiconducting material;

supporting the substrate on the support; and

moving the lift pin to contact the substrate.

20. A method according to claim 19 comprising supporting the substrate on the support by generating an electrostatic chucking force.

21. A method according to claim 20 comprising flowing residual electrostatic charge from the substrate through the lift pin to a current sink.

22. A method according to claim 19 wherein the semiconducting material is sufficiently thick to provide a resistance over the length of the pin of at least about 0.5 MΩ.

23. A method according to claim 19 wherein the semiconducting material comprises silicon carbide.

24. A method according to claim 19 wherein the semiconducting material comprises titanium diboride.

25. A method of processing a substrate in a chamber, the method comprising:

providing a support in the chamber, the support comprising an electrostatic chuck and a lift pin comprising semiconducting material;

generating an electrostatic chucking force to support the substrate on the support;

providing energized process gas in the chamber; and

moving the lift pin to contact the substrate to dechuck the support.

26. A method according to claim 25 comprising flowing residual electrostatic charge from the substrate through the lift pin to a current sink.

27. A method according to claim 25 wherein the semiconducting material is sufficiently thick to provide a resistance over the length of the pin of at least about 0.5 MΩ.

28. A method according to claim 25 wherein the semiconducting material comprises silicon carbide.

29. A method according to claim 25 wherein the semiconducting material comprises titanium diboride.

30. A method of fabricating a lift pin usable in a substrate support in a chamber, the method comprising:

providing a body comprising semiconducting material and

forming the body into the lift pin.

31. A method according to claim 30 wherein the body is formed from a unitary piece of semiconducting material.

32. A method according to claim 30 comprising forming an electrically conducting upper portion and an electrically conducting lower portion on the body.

33. A method according to claim 30 comprising providing sufficient semiconducting material to provide a resistance over the length of the lift pin of at least about 0.5 MΩ.

34. A method according to claim 30 comprising doping the semiconducting material sufficiently to provide a resistance over the length of the lift pin of at least about 0.5 MΩ.

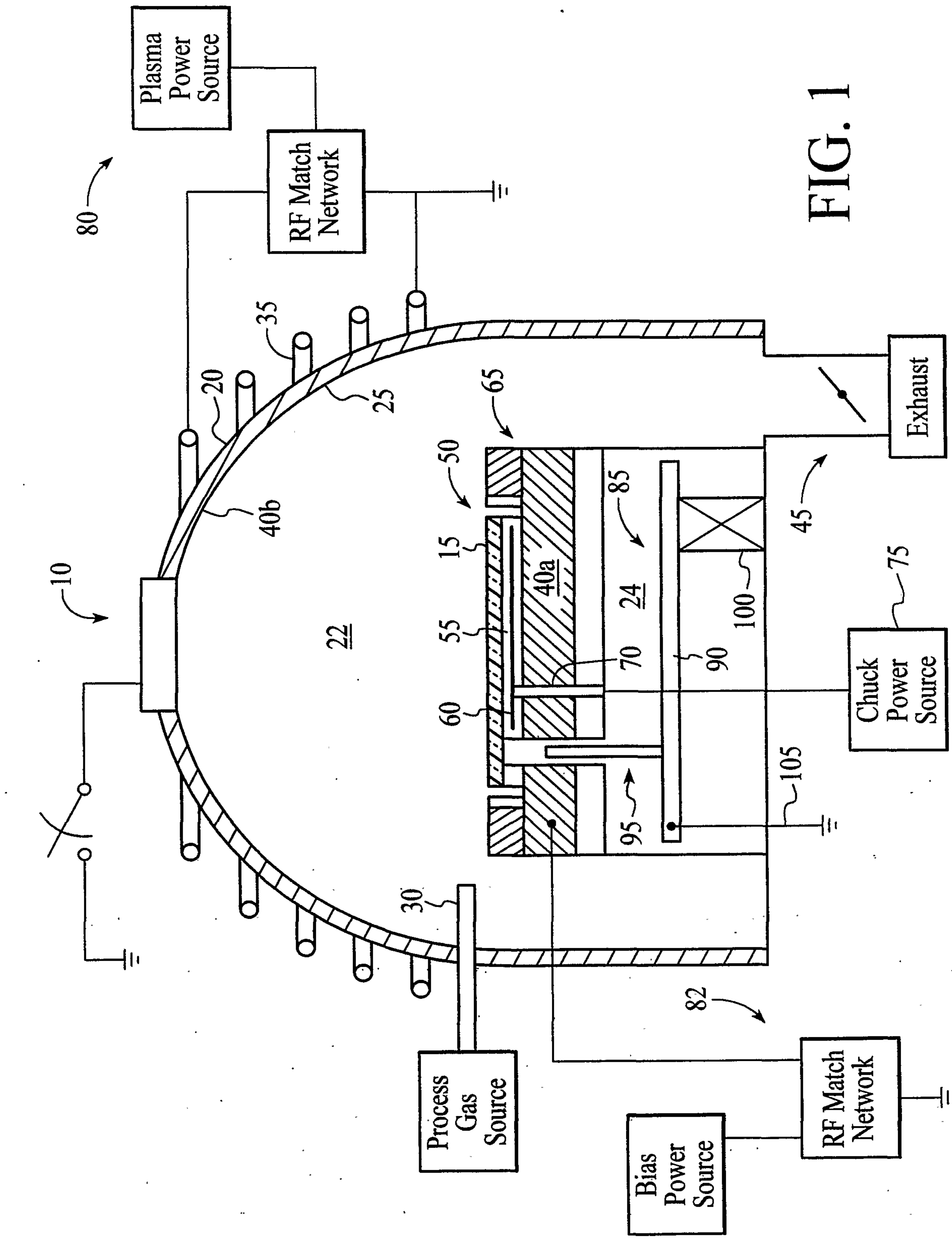
Plasma Power Source
RF Match Network
80
10
20
35
25
40b
65
50
15
55
40a
85
22
24
70
90
60
100
95
105
45
Exhaust
Chuck Power Source
75
30
82
Process Gas Source
RF Match Network
Bias Power Source

FIG. 1

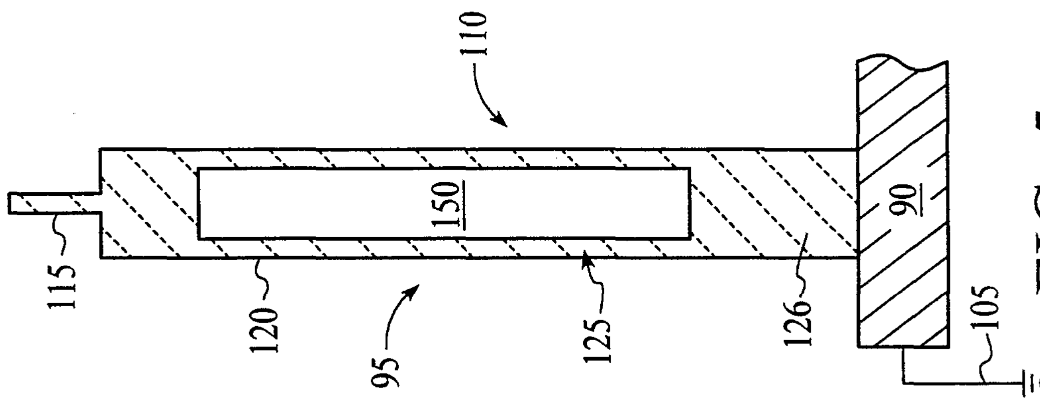

FIG. 5

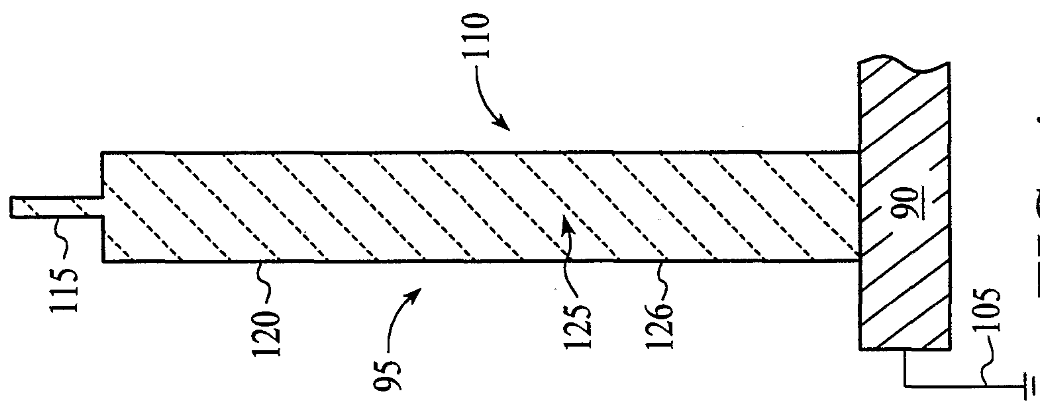

FIG. 4

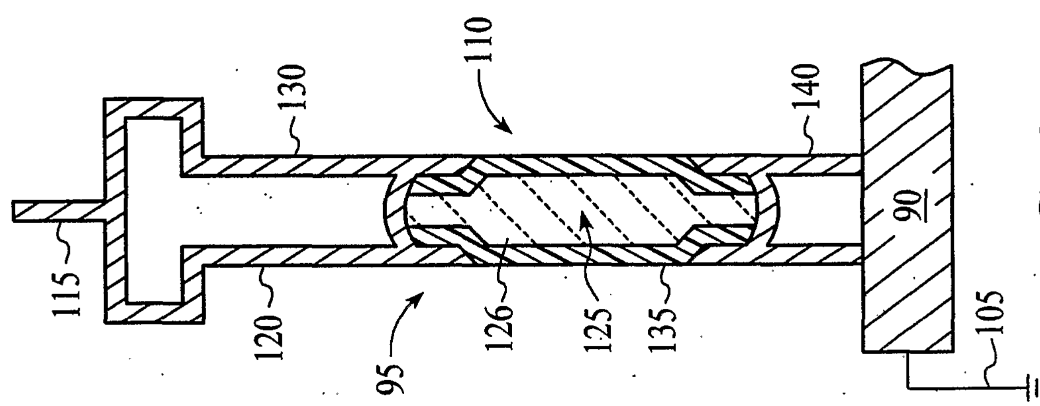

FIG. 3

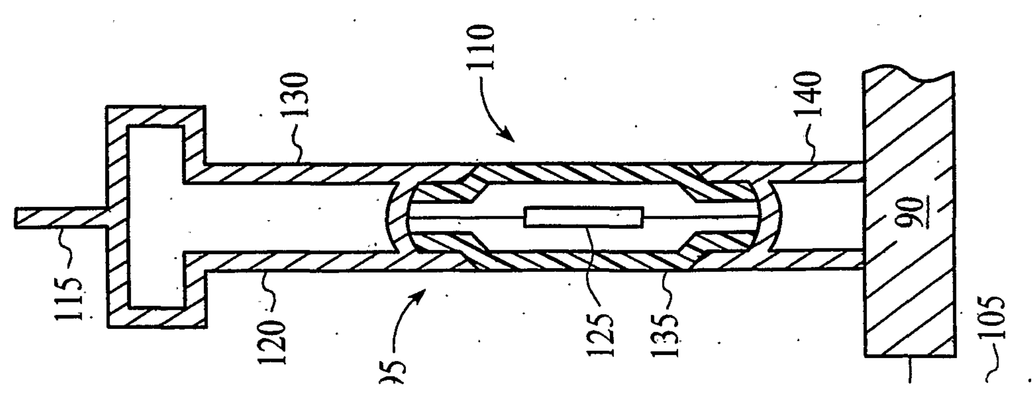

FIG. 2